List of tide gauge stations co-located with a permanent GNSS station in Europe

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Co-location of a tide gauge with a permanent GNSS (Global Navigation Satellite System) station is crucial for referring sea level data to the ellipsoid (global reference, instead of local reference) and to distinguish changes in absolute mean sea level from the land movements at each site (Woodworth et al., 2012, IOC, 2016). The distance between the GNSS and the tide gauge station is critical: if too far away, the vertical land movement derived from the GNSS station might be different from the one at the tide gauge site; in this case a periodic geodetic tie between both stations is required, and this is not always available (Woodworth et al. 2017 explain this in detail). However, most of existing tide gauges provide just the sea level relative to a Tide Gauge Bench Mark (TGBM) on land.

In Europe, sea level data from tide gauges are now available in the Copernicus Marine Service data portals: CMEMS In-Situ TACs: http://www.marineinsitu.eu/dashboard/, in addition to other oceanographic parameters, while maintaining the contribution to traditional tide gauge data portals such as the Global Ocean Observing System (GLOSS, IOC, UNESCO) or the Permanent Service for Mean Sea Level (PSMSL). The SONEL (Système d'Observation du Niveau des Eaux Littorales, http://www.sonel.org/)) is a data bank hosted at the University of La Rochelle, in La Rochelle, France, that acts as the official data centre for GNSS information for the GLOSS (Global Sea Level Observing System) program.

The objective of this report is to provide users of tide gauge data, especially the altimetry and modelling communities within CMEMS, a list of the tide gauges available through the Copernicus Marine Service CMEMS, co-located with a permanent GNSS station and, therefore, with information of ellipsoidal height.

From an estimated total number of 675 tide gauges in operation in and around Europe, obtained from a survey launched in 2016 by the EuroGOOS Tide Gauge Task Team, SONEL reported in June 2017 a list of 191 tide gauge stations with a GNSS station nearby, that could potentially allow the definition of the ellipsoidal height and vertical velocity of the tide gauge. This list included columns with the Permanent Service for Mean Sea Level (PSMSL) *id* (RLR id) and name, longitude and latitude of the tide gauge station, acronym or code for the nearest GNSS station, colocation distance in meters between the tide gauge and the GNSS station, GNSS data availability and geodetic tie availability.

As can be seen in figure 1, from these 191 tide gauges extracted from SONEL data bank, the majority of them are between 1 and 10 km apart from the closest GNSS station; therefore, it will be difficult to determine the ellipsoidal height and vertical land movement at these stations without precise levelling information. The SONEL group is trying to update this information from the different national institutions. A summary will be presented here based on the subset of tide gauges with GNSS co-location distance below 1 km, displayed in figure 2. In this figure, green dots correspond to those stations for which geodetic tie information is available in SONEL data bank and, therefore, the best candidates to determine absolute mean sea level changes at this moment. Based on this subset of tide gauges, the initial SONEL list has been completed with an additional column with the CMEMS name for those tide gauges in the list that are available in the CMEMS In-Situ Tac's (red contoured dots in figure 2 correspond to these tide gauges). From this figure we can see that there are only 27 tide gauges in CMEMS at this moment that fulfill the following conditions: GNSS station co-located below 1 km and a tie connection available in SONEL.

These 27 stations are listed in Annex A attached to this document, including estimates of the ellipsoidal height of the Tide Gauge Bench Mark and vertical land velocity of the GNSS station from the ULR6a solution computed by SONEL, if available (http://www.sonel.org/-Vertical-land-movement-estimate-.html?lang=en, Santamaría-Gómez et.al, 2017). The ULR6a velocities have been derived over a minimum of 3 years of GNSS data between two position discontinuities (GNSS stations can be indeed affected by sudden displacements due to equipment change (antenna, receiver, …) or geophysical processes (earthquakes). Santamaría-Gómez & Mémin, 2015 affirm that unless an accurate loading model is available, a decade of continuous data is required to mitigate the impact of the interannual loading deformation on secular velocities. Thus, it is highly recommended to maintain the GNSS station in a long-term way, with equipment changes only when it is strictly necessary.

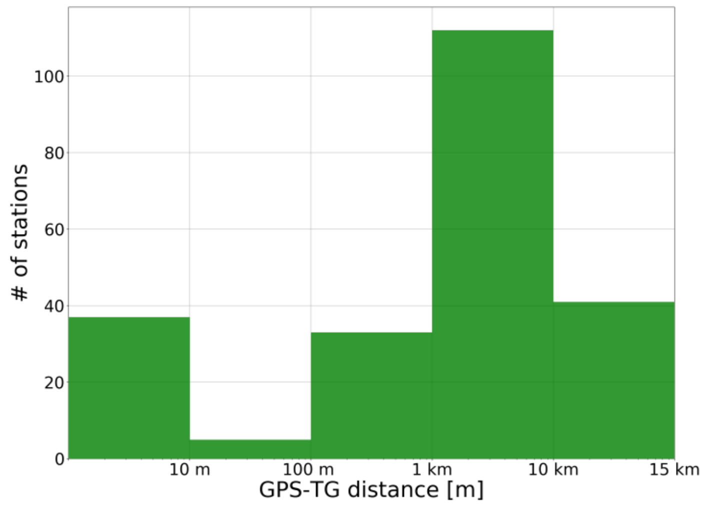

Figure 1: histogram showing the distribution of the colocation distances TG-GNSS stations in Europe, from SONEL data bank. It shows that many GNSS stations are quite far from the tide gauge (>1 km) and so levelling between the tide gauge and the GNSS station is difficult and expensive.

The tide gauge ellipsoidal height is a very useful information to obtain geocentric sea level measurements, from the combination of tide gauge observations, the collocated GNSS data processing and the geodetic tie between the tide gauge and the GNSS marker. If a GNSS station is not yet in SONEL, the ellipsoidal height can be processed by the NRCAN CSRS-PPP on-line software (https://webapp.geod.nrcan.gc.ca/geod/tools-outils/ppp.php) from a daily GNSS observation file.

Ideally, in the coming years more new stations will be based on a combination of sea level sensor and GNSS receiver at the same site, what will reduce this uncertainty associated to the levelling. This is in fact already being implemented in several countries (e.g. figure 3), although depending on the characteristics of the station this solution will not often be possible.

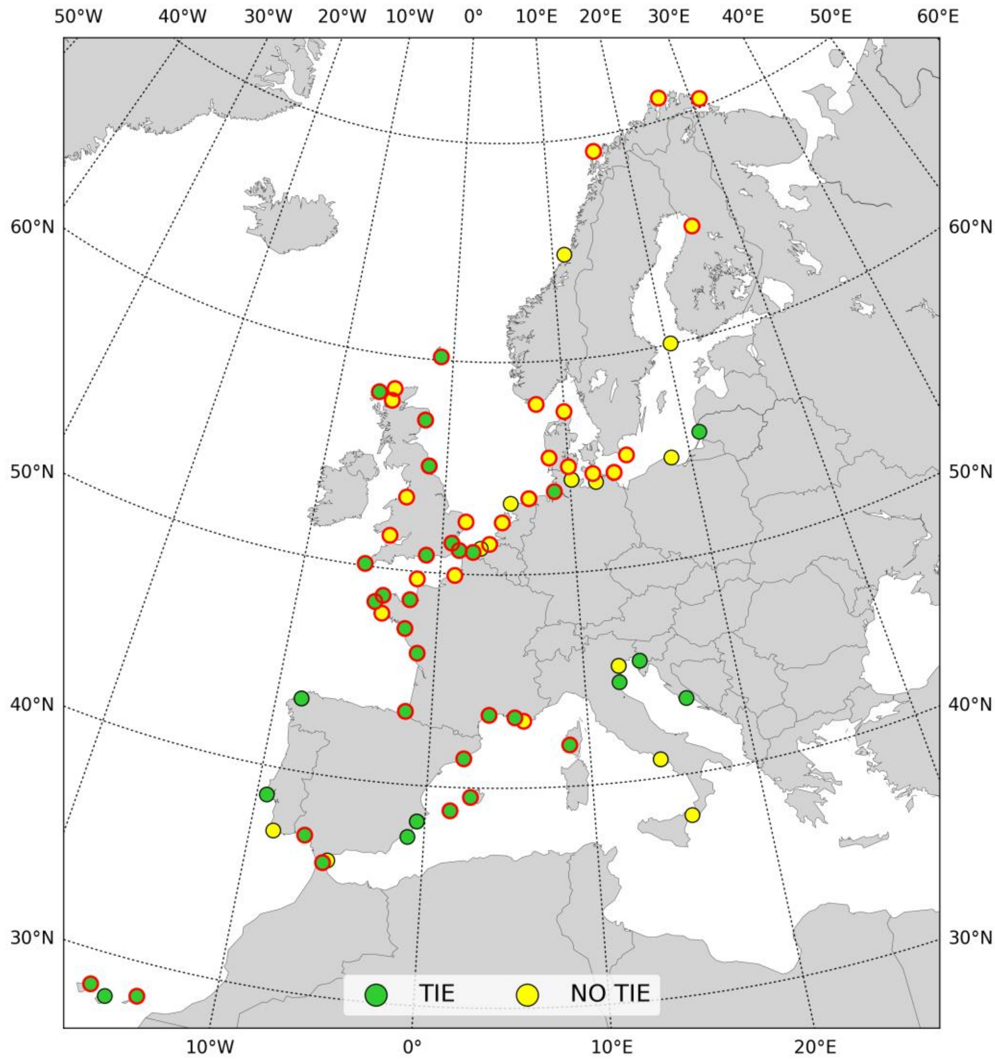

Figure 2: GNSS@TG colocation sites with a colocation distance < 1 km. Green points are for stations for which the geodetic tie is available in SONEL, yellow points are for stations for which this geodetic tie is not available in SONEL. Red contour dots are stations that are listed in the CMEMS database.

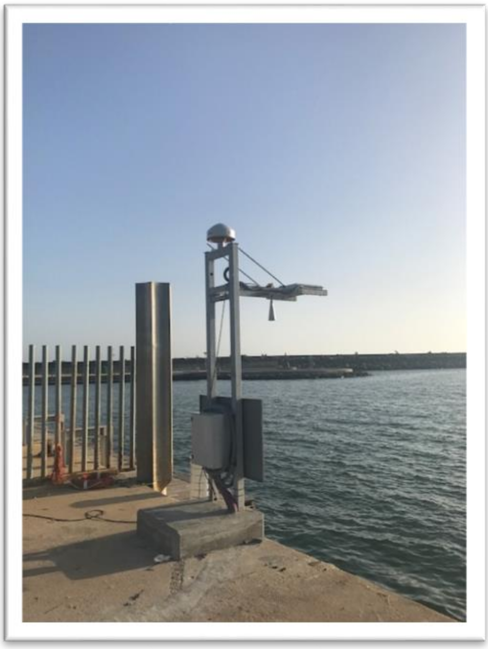

Figure 3: GNSS@TG station installed recently at Huelva Tide Gauge station (REDMAR, Spain).

References

- Intergovernmental Oceanographic Commission (2016), Manual on Sea Level measurement and interpretation, IOC Manuals Guides 14, vol. 1–4, Paris, http://www.psmsl.org/train_and_info/training/manuals/.

- Santamaría-Gómez A., Gravelle M., Dangendorf S., Marcos M., Spada G., Wöppelmann G. (2017), Uncertainty of the 20th century sea-level rise due to vertical land motion errors. *Earth and Planetary Science Letters*, 473, 24-32.

- Santamaría-Gómez A., Mémin A. (2015), Geodetic secular velocity errors due to interannual surface loading deformation, *Geophysical Journal International*, Volume 202, Issue 2, Pages 763–767, https://doi.org/10.1093/gji/ggv190

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- Woodworth, P. L., G. Wöppelmann, M. Marcos, M. Gravelle, and R. M. Bingley (2017), Why we must tie satellite positioning to tide gauge data, Eos, 98, doi:10.1029/2017EO064037.

Annex A: LIST OF TIDE GAUGES IN CMEMS CO-LOCATED WITH A GNSS PERMANENT STATION (MAY 2018):

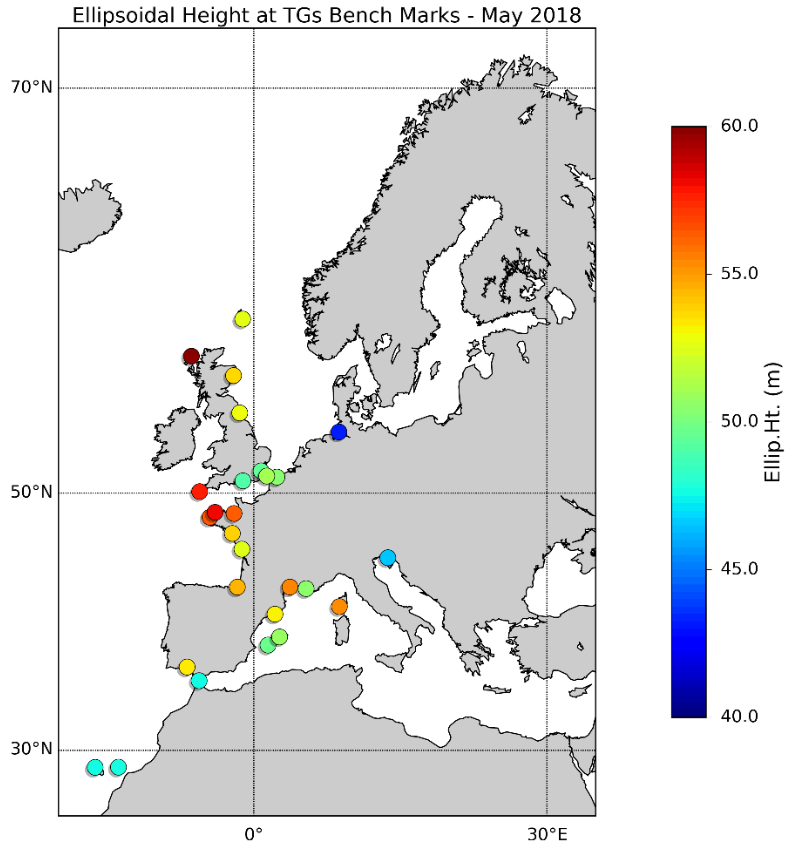

Figure 4: map of ellipsoidal heights for the **27 tide gauges** fulfilling the following conditions:

- Data available in CMEMS data portals (*) (InSitu TAC's)
- Geodetic information available from SONEL or national institutions
- Tide gauge – Permanent GNSS station distance < 1 km
- Geodetic tie available between the Tide Gauge Bench Mark (TGBM) and the GNSS stations.

Table 2: Example of ellipsoidal heights at the TGBM, depending on the source:

	Spanish IGN	**NGL Solution**	**SONEL Solution**
Barcelona	53.249 m	53.236 m	
Palma de Mallorca	50.775 m	50.753 m	
Ibiza	49.693 m		49.696 m
Tarifa	47.556 m		47.560 m

* CMEMS In-Situ Tacs: http://www.marineinsitu.eu/dashboard/

IMPORTANT NOTE: There are many more stations in Europe with a GNSS nearby. For those interested this will be easy to find in SONEL website (http://www.sonel.org/-GPS-.htm). However, only these 26 fulfil the requirements for the objective of this report at the time of writing. It is expected that more stations will be added to this living list as far as additional information (e.g. levelling data, installation of new stations, etc) become public or provided by national institutions.

#RLRID	CMEMS_NAME	LONG (deg)	LAT (deg)	GNSS ID	DIST (m)	TGBM_name	TGBM_h (m)	ULR6a_GPS_vel (mm/yr)
1929	**AjaccioTG**	8.762850	41.922798	AJAC	530	FM"-3	55.373	0.39 +/- 0.14
1	**BrestTG**	-4.494838	48.382850	BRST	292	A	56.603	-0.02+/-0.11
468	**DunkerqueTG**	2.366698	51.048091	DUNQ	1	A	50.364	UNKN
466	**LaRochelleTG**	-1.220736	46.158478	LROC	121	A	52.563	-0.14+/-0.16
61	**MarseilleTG**	5.353860	43.278801	MARS	1	A	50.587	-0.24 +/- 0.18
469	**SocoaTG**	-1.681623	43.395239	SCOA	1	D	54.560	-2.7 +/- 0.28
457	**SaintNazaireTG**	-2.200000	47.270000	STNA	450	A	53.904	UNKN
958	**SeteTG**	3.699110	43.397598	SETE	1	H	55.591	-0.87 +/- 0.27
1347	**RoscoffTG**	-3.965860	48.718399	ROTG	1	A	58.234	-1.29+/-0.33
454	**SaintMaloTG**	-2.028180	48.641102	SMTG	5	C	56.398	-0.63+/-0.46
202	**Newlyn**	-5.542833	50.103000	NEWL	1	SW46762855	57.742	-0.21+/-0.13
361	**Aberdeen**	-2.077361	57.144056	ABER	0	NJ95250590	53.797	0.9+/-0.22
95	**NorthShields**	-1.439778	55.007444	NSTG	1	NZ35926823	52.931	0.56+/-0.37
3	**Sheerness**	0.743444	51.445639	SHEE	1	TQ90807549	49.435	1.09+/-0.2
830	**Lerwick**	-1.140306	60.154028	LWTG	1	HU47834129	52.652	0.55+/-0.28
314	**Stornoway**	-6.388972	58.207806	SWTG	1	NB42283264	60.063	0.6+/-0.3
1932	**IbizaTG**	1.449840	38.911230	IBIZ	78	IB1	49.696	-2.36+/-0.18
350	**Portsmouth**	-1.111250	50.802250	PMTG	7	SU62700053	49.089	0.04+/-0.23
255	**Dover**	1.322667	51.114389	DVTG	1	TR31934074	51.088	UNKN
7	**Cuxhaven**	8.716667	53.866667	TGCU	1	11007	43.134	0.01+/-0.86

Table 1: Ellipsoidal heights and vertical land velocity information for tide gauges closer than 1 km (and geodetically tied) to a permanent GNSS station: ellipsoidal heights provided at the Tide Gauge Bench Mark (all from the ULR6a solution (http://www.sonel.org/-Vertical-land-movement-estimate-.html?lang=en) except Barcelona and Palma de Mallorca, obtained from the NGL solution (http://geodesy.unr.edu/, and Huelva and Ibiza, provided by the Spanish IGN: ftp://ftp.geodesia.ign.es/ERGNSS). All heights are expressed in the **IGS08 reference frame at the epoch 2017**. Combining the GPS processing and propagation and the levelling errors, the estimated accuracy of these heights is assumed to be around 2cm. Vertical velocities were estimated at the GNSS site, for those stations with several years of GNSS data.

For more detailed information about the computation of these values: http://www.sonel.org/-GPS-.htm, http://geodesy.unr.edu/, ftp://ftp.geodesia.ign.es/ERGNSS.

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2054	**TarifaTG**	-5.603510	36.006460	TARI	240	NGAB_MAR	47.560	0.21+/-0.59
1811	**BarcelonaTG**	2.165700	41.341770	BCL1	0	Clavo_146	53.236	UNKN
2061	**PalmadeMallorcaTG**	2.637480	39.560150	MAL1	0	NGAB_Mareog_Palma	50.753	UNKN
1883	**HuelvaTG**	-6.833690	37.132020	HUE1	0	SSPD	53.384	UNKN
1009	**Koper**	13.72455	45.54811	KOPE	0	R 5486	46.472	-0.33+/-0.27
1803	**TenerifeTG**	-16.241117	28.477217	TN01	1	SS412	47.607	-1.42 +/- 0.2
2048	**FuerteventuraTG**	-13.858215	28.492563	FUER	720	NGAB-MAREO	47.639	UNKN

Table 1 (cont.): Ellipsoidal heights and vertical land velocity information for tide gauges closer than 1 km (and geodetically tied) to a permanent GNSS station: ellipsoidal heights provided at the Tide Gauge Bench Mark (all from the ULR6a solution (http://www.sonel.org/-Vertical-land-movement-estimate-.html?lang=en) except Barcelona and Palma de Mallorca, obtained from the NGL solution (http://geodesy.unr.edu/, and Huelva and Ibiza, provided by the Spanish IGN: ftp://ftp.geodesia.ign.es/ERGNSS). All heights are expressed in the **IGS08 reference frame at the epoch 2017**. Combining the GPS processing and propagation and the levelling errors, the estimated accuracy of these heights is assumed to be around 2cm. Vertical velocities were estimated at the GNSS site, for those stations with several years of GNSS data.

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